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EXPERIMENTAL DETERMINATION OF THE HYDRODYNAMIC LOADING FUNCTION--ETC(U)
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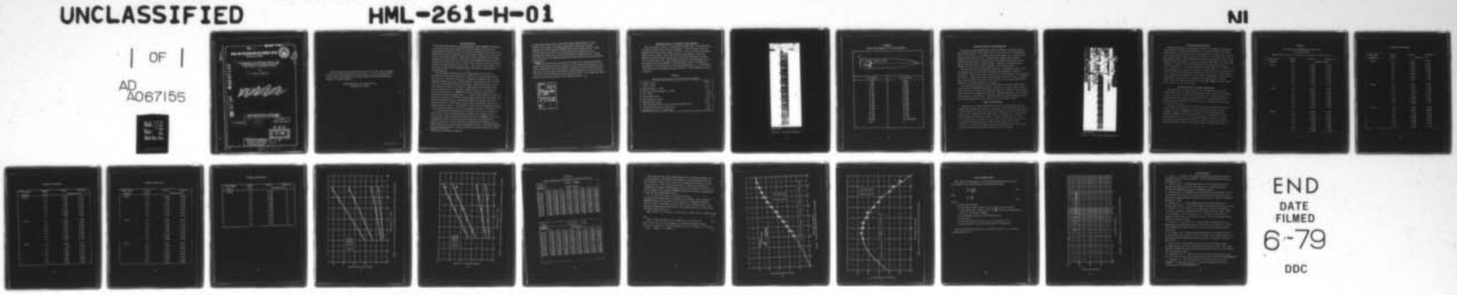

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NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Washington, D.C. 20007

EXPERIMENTAL DETERMINATION OF THE HYDRODYNAMIC LOADING FUNCTIONS FOR THE T-5 TRAILING FAIRING

by

Chester O. Walton

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HYDROMECHANICS LABORATORY

TEST AND EVALUATION REPORT

March 1968 24p.

Report HML-261-H-01

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The Naval Ship Research and Development Center is a U.S. Navy center for laboratory effort directed at achieving improved sea and air vehicles. It was formed in March 1967 by merging the David Taylor Model Basin at Carderock, Maryland and the Marine Engineering Laboratory at Annapolis, Maryland.

Naval Ship Research and Development Center
Washington, D.C. 20007

INTRODUCTION

The Naval Ship Research and Development Center (NSRDC) established a broad research project under the Variable Depth Sonar Exploratory Development Program directed toward the development of improved experimental and analytical techniques for predicting the steady-state characteristics of cable-towed systems. The project, to be completed in two phases, consists of (a) basin tests to acertain the hydrodynamic loading functions of a faired cable and (b) sea tests to verify and to correlate basin test data and theoretical predictions with sea test data. This report is the subject of the first phase of the project dealing with the basin tests to determine the loading functions. Over

The differential equations for describing mathematically the two-dimensional equilibrium configuration and forces of a cable-body system[1] were derived a number of years ago. Solutions for these equations can be obtained numerically using a digital computer[2] provided the body characteristics and cable loading functions are known. The characteristics of the towed body can either be calculated or experimentally determined using various mechanisms.[3,4] The cable loading functions are not generally known and past practice at NSRDC has been to use the loading functions proposed by different investigators.[1,5,6] Some of these functions are based on theory and others are based on limited experimental data; but in the case of faired towcables there is considerable doubt as to whether any of the existing functions can accurately represent the hydrodynamic loading on an arbitrary faired towcable. This doubt is borne out in the difference obtained in the tangential loading of several fairing shapes recently investigated.[7,8,9]

In view of the aforementioned uncertainties, the limited experimental data on which to base loading functions, and the lack of experiments to ascertain the validity of proposed loading functions, the NSRDC project was established to obtain the two-dimensional steady-state hydrodynamic loading functions of a faired towcable for application to existing and future VDS systems and to ascertain the validity and accuracy of the experimentally obtained loading functions. The experimental approach consisted of towing

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[1] References are listed on page 22.

a rigid faired-cable model in the David Taylor Model Basin at various speeds, cable angles, and model submergences and measuring the hydrodynamic force using the DTMB Cable Fairing Dynamometer. These data were then used with a curve-fitting computer program to obtain mathematical expressions for the hydrodynamic loading functions. These data will be used in subsequent predictions and sea tests in the second phase of the project.

~~This~~ The report describes the faired-cable model, the towing dynamometer, and the test procedures; gives sample curves of normal and tangential forces versus submergence for various speeds; presents tabulated loading functions; gives plots of the normal and tangential loading functions versus cable angle and a plot of drag coefficient versus Reynolds number; and provides the mathematical expressions derived for the loading functions.

DESCRIPTION OF A FAIRED-CABLE MODEL

The test model consists of a simulated stranded cable, a trailing fairing and equally spaced clips as shown in Figure 1. The simulated cable was geometrically scaled with a linear ratio of 0.175 from a 0.35-inch-diameter double-armored cable. The cable consists of twenty-four 0.219-inch-diameter strands of copper tubing with a 16.45-inch left-hand lay joined to a seamless steel tube. The trailing fairing was scaled geometrically to the proper size using a DTMB T-5 fairing shape, which is considered a continuation of the fairing series contained in Reference 10 . The physical characteristics of the model are given in Table 1, and the offsets are given in Table 2.

TABLE 1

Physical Characteristics of the Faired-Cable Model

Length, inches	89.25
Chord, inches	10.6
Cable diameter, inches	2.0
Maximum fairing thickness, inches	1.67
Gap, inches	0.186
Clip width, inches	1.50
Clip thickness, inches	0.09
Clip spacing, inches	10.0
Ratio of wetted surface area to projected frontal area	11.49
Projected frontal area, square feet	1.24
Wetted surface area, square feet	14.25

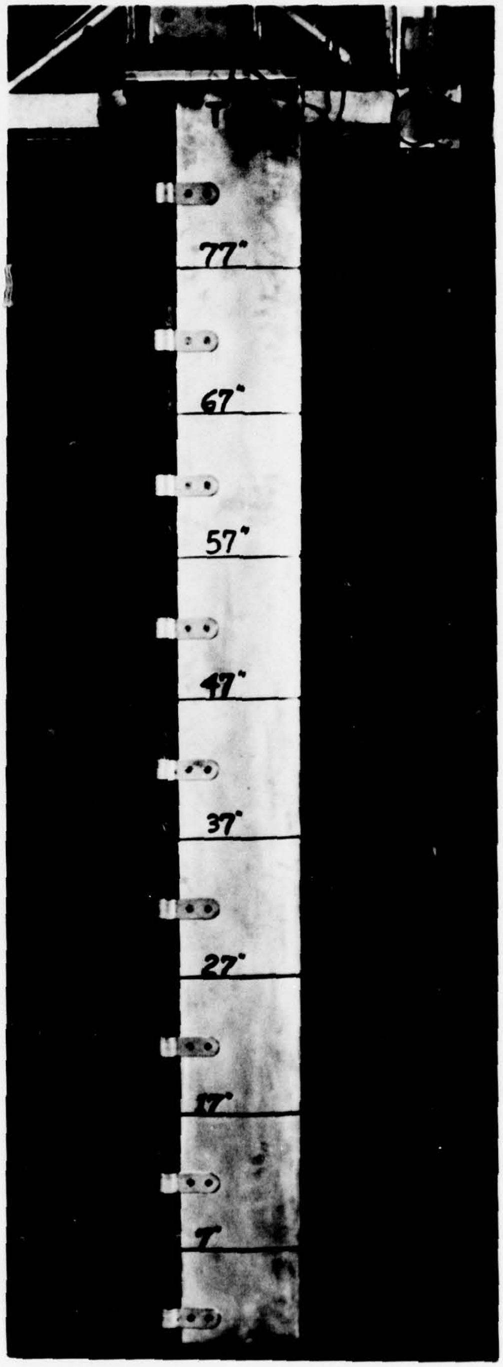

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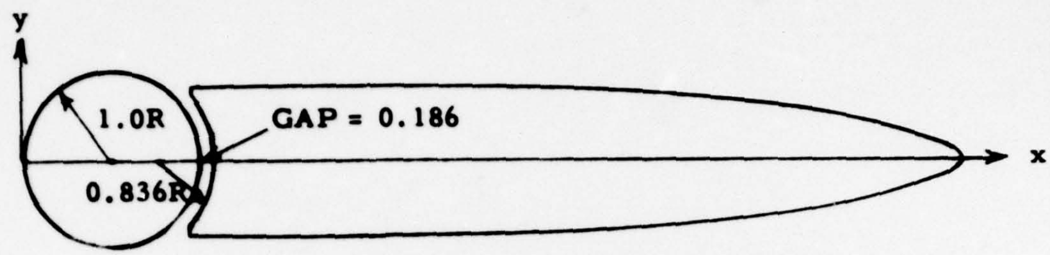
Figure 1 - Faired-Cable Model

TABLE 2

Dimensional Offsets for T-5 Fairing Model



x in inches	± y in inches
1.921	0.8365
3.909	0.8365
4.578	0.8359
5.247	0.8312
5.916	0.8186
6.586	0.7946
7.255	0.7547
7.924	0.6955
8.594	0.6126
9.262	0.5020
9.598	0.4344
9.931	0.3550
10.267	0.2513
10.434	0.1775
10.464	0.1160 Radius
10.6	0

DESCRIPTION OF DYNAMOMETER

The cable-fairing dynamometer is shown in Figure 2 with the faired-cable model attached. The normal force X, lateral force Y, and tangential force Z on the model are sensed by 4-inch-cube modular force gages of the type described in Reference 3. Interchangeable gages with capacities ranging from 50 pounds to 1000 pounds are available so that high accuracy can be maintained over a range of speeds. However, the dynamometer design limits any of the three component forces to 500 pounds.

The tilt-table angle is adjustable so that the cable angle φ relative to the free stream may be varied from 90 degrees to 30 degrees in 5-degree increments. The vertical position of the model and tilt table is also adjustable by means of a hoist to give model submergences from 0 to 7 feet. A weight-pan system provides a means of counterbalancing the model weight on the gages at each submergence and cable angle.

The instrumentation used in this test consisted of three modular-gage controls units, two integrating digital voltmeters to record X and Z forces, and a strip-chart recorder to monitor the Y forces. The X, Y, and Z forces were measured with 200-pound-capacity, 1000-pound-capacity and 50-pound-capacity gages, respectively. Carriage speed was measured using a photocell pick-up and gear with the signal fed to an electronic counter.

TEST PROCEDURES

The model was towed in the high-speed basin at cable angles ranging from 90 to 30 degrees in 5-degree increments. The model submergence was varied from 67 to 27 inches in 10-inch increments at various towing speeds from 2.5 to 6.5 knots for each cable angle. In addition, for a cable angle of 90 degrees, the model was towed at various speeds from 1 to 7 knots at all submergences. The X, Y, and Z forces and carriage speeds were recorded for all test conditions. The Y-force recording was used primarily as a basis for alining the model with the flow and as a means to monitor the lateral oscillations of the model at test speeds.

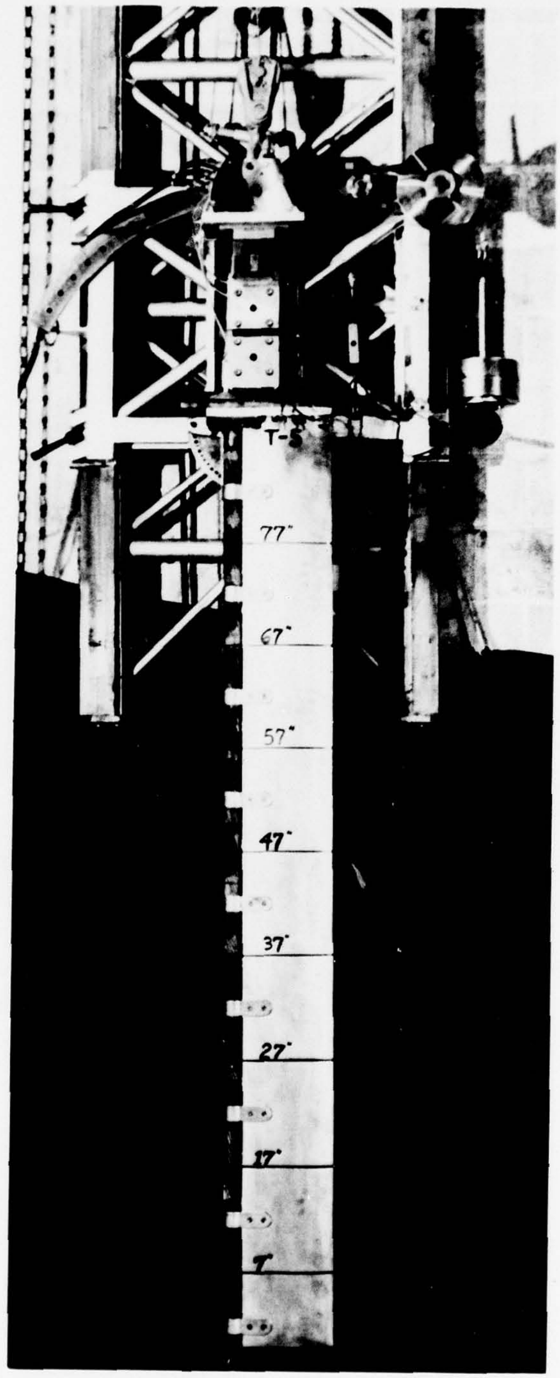


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Figure 2 - Cable-Fairing Dynamometer

HYDRODYNAMIC FORCE

The two-dimensional, steady-state, normal and tangential hydrodynamic forces X and Z are tabulated in Table 3 for each test condition. Since the measured forces were generated by a finite surface-piercing model, the test data contain both end effects and surface effects. To eliminate these effects, the values in Table 3 were obtained by the following reduction technique. The X and Z forces are plotted as a function of model submergence for each angle and speed. Typical curves for the X and Z forces are shown in Figure 3 and 4, respectively, for various speeds and a cable angle of 55.1 degrees. As the submergence is increased, a length is reached after which the increase in the X and Z forces is directly proportional to the increase in submergence, i.e., end and surface effects do not vary with submergence. Thus, the two-dimensional normal force or tangential force per unit length shown in Table 3 for each angle and speed is the slope, $\frac{\Delta X}{\Delta s}$ or $\frac{\Delta Z}{\Delta s}$, of the appropriate curve, where s is the submergence.

HYDRODYNAMIC LOADING FUNCTIONS

The hydrodynamic loading functions are defined as the ratio of the steady-state, two dimensional, hydrodynamic forces acting on an element of cable at an angle φ to the free stream to the force when the element is normal to the free stream (φ = 90 degrees). For a given faired-cable geometry and speed, these loading functions are assumed to be dependent only on the cable angle.

The normal and tangential loading functions were determined using the slopes of the force-submergence curves tabulated in Table 3 and the computer program, BVPDE3, developed by the Applied Mathematics Laboratory (AML). The slopes at each angle are divided by the slope of the normal-force curve at an angle of 90 degrees to obtain the loading function values for each speed and angle. These values, both normal and tangential, for the subject cable-fairing model are tabulated in Table 4.

TABLE 3

Two-Dimensional Hydrodynamic Force for T-5 Cable Fairing

(These data have been corrected for near-surface and end effects.)

Cable Angle, degrees	Speed, knots	Normal (pounds per foot)	Tangential (pounds per foot)
30.40	2.5	0.296	0.211
	3.0	0.430	0.302
	3.5	0.572	0.413
	4.0	0.694	0.532
	5.0	1.037	0.835
	5.5	1.321	1.006
	6.0	1.495	1.192
	6.5	1.712	1.397
35.30	2.5	0.361	0.223
	3.0	0.438	0.321
	3.5	0.654	0.440
	4.0	0.783	0.560
	5.0	1.225	0.892
	5.5	1.552	1.088
	6.0	1.816	1.281
	6.5	2.133	1.509
40.30	2.5	0.401	0.227
	3.0	0.604	0.317
	3.5	0.755	0.422
	4.0	0.996	0.541
	5.0	1.539	0.845
	5.5	1.826	1.006
	6.0	2.198	1.193
	6.5	2.609	1.404

TABLE 3 (Continued)

Cable Angle, degrees	Speed, knots	Normal	Tangential
		pounds per foot	
45.20	2.5	0.437	0.227
	3.0	0.692	0.317
	3.5	0.872	0.421
	4.0	1.164	0.549
	5.0	1.788	0.849
	5.5	2.180	1.012
	6.0	2.644	1.204
	6.5	3.021	1.415
50.10	2.5	0.551	0.206
	3.0	0.790	0.281
	3.5	1.046	0.389
	4.0	1.342	0.499
	5.0	2.071	0.763
	5.5	2.580	0.923
	6.0	2.996	1.091
	6.5	3.524	1.271
55.10	2.5	0.598	0.192
	3.0	0.867	0.281
	3.5	1.107	0.383
	4.0	1.485	0.494
	5.0	2.286	0.708
	5.5	2.855	0.943
	6.0	3.321	1.121
	6.5	3.969	1.317

TABLE 3 (Continued)

Cable Angle, degrees	Speed, knots	Normal	Tangential
		pounds per foot	
60.10	2.5	0.702	0.162
	3.0	1.001	0.233
	3.5	1.342	0.313
	4.0	1.700	0.419
	5.0	2.690	0.648
	5.5	3.296	0.771
	6.0	3.808	0.925
	6.5	4.495	1.086
64.85	2.5	0.759	0.146
	3.0	1.083	0.207
	3.5	1.448	0.289
	4.0	1.875	0.362
	5.0	2.971	0.561
	5.5	3.636	0.685
	6.0	4.300	0.815
	6.5	4.988	0.952
69.85	2.5	0.825	0.133
	3.0	1.148	0.192
	3.5	1.557	0.263
	4.0	1.966	0.345
	5.0	3.089	0.535
	5.5	3.882	0.644
	6.0	4.421	0.768
	6.5	5.247	0.897

TABLE 3 (Continued)

Cable Angle, degrees	Speed, knots	Normal	Tangential
		pounds per foot	
74.80	2.5	0.859	0.098
	3.0	1.222	0.131
	3.5	1.673	0.172
	4.0	2.121	0.229
	5.0	3.343	0.346
	5.5	4.134	0.416
	6.0	4.799	0.495
	6.5	5.604	0.576
79.70	2.5	0.901	0.087
	3.0	1.270	0.113
	3.5	1.754	0.153
	4.0	2.198	0.199
	5.0	3.446	0.298
	5.5	4.311	0.351
	6.0	4.994	0.424
	6.5	5.984	0.494
84.70	2.5	0.936	0.051
	3.0	1.333	0.073
	3.5	1.831	0.092
	4.0	2.346	0.121
	5.0	3.621	0.187
	5.5	4.392	0.216
	6.0	5.219	0.251
	6.5	6.143	0.304

TABLE 3 (Continued)

Cable Angle, degrees	Speed, knots	Normal	Tangential
		pounds per foot	
89.94	1.0	0.196	0
	1.5	0.345	0
	2.0	0.589	0
	2.5	0.940	0
	3.0	1.347	0
	3.5	1.842	0
	4.0	2.400	0
	4.5	3.018	0
	5.0	3.733	0
	5.5	4.476	0
	6.0	5.363	0
	6.5	6.235	0
	7.0	7.191	0

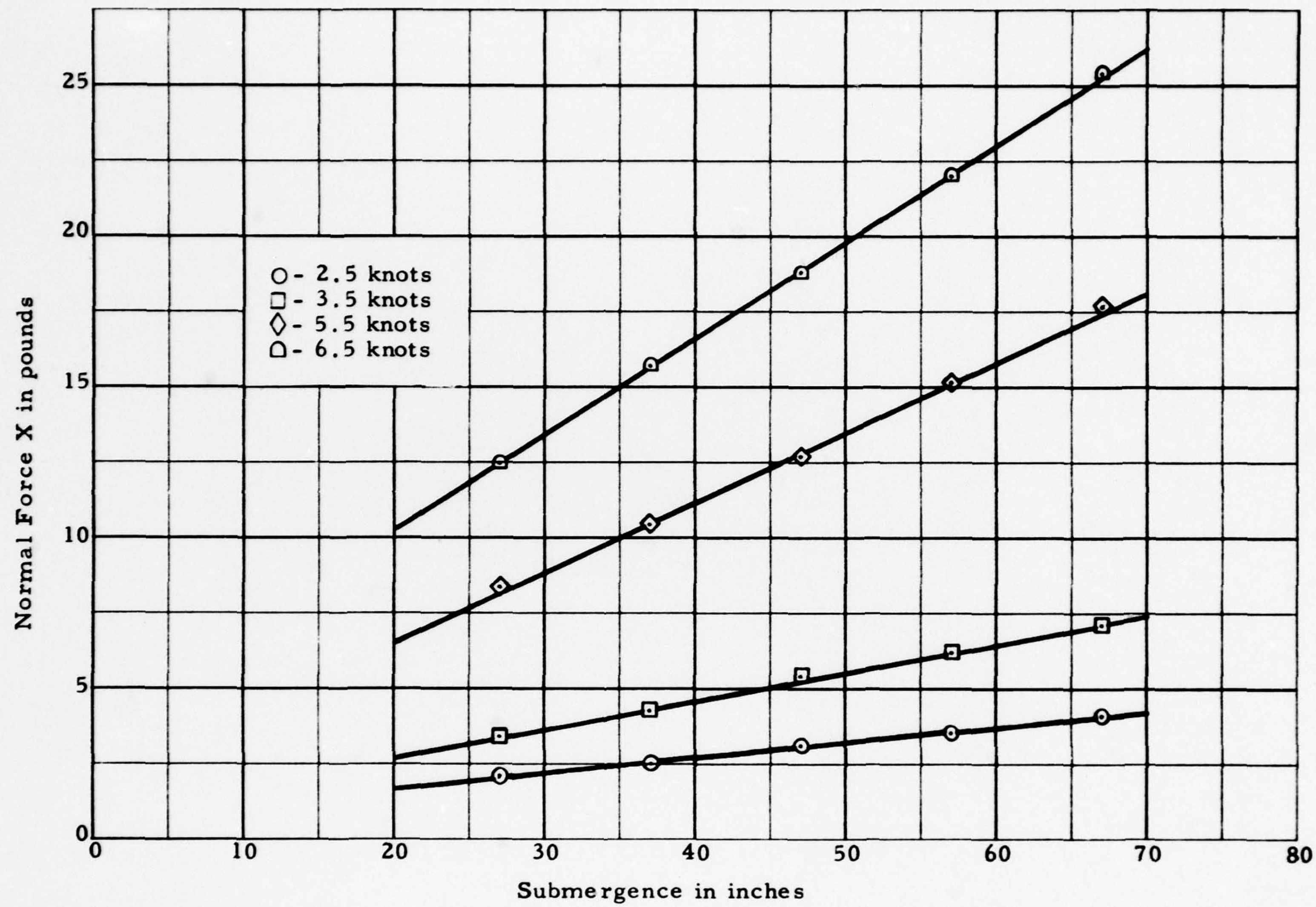

Figure 3 - Normal Force Versus Submergence for a Cable Angle of 55.10 Degrees

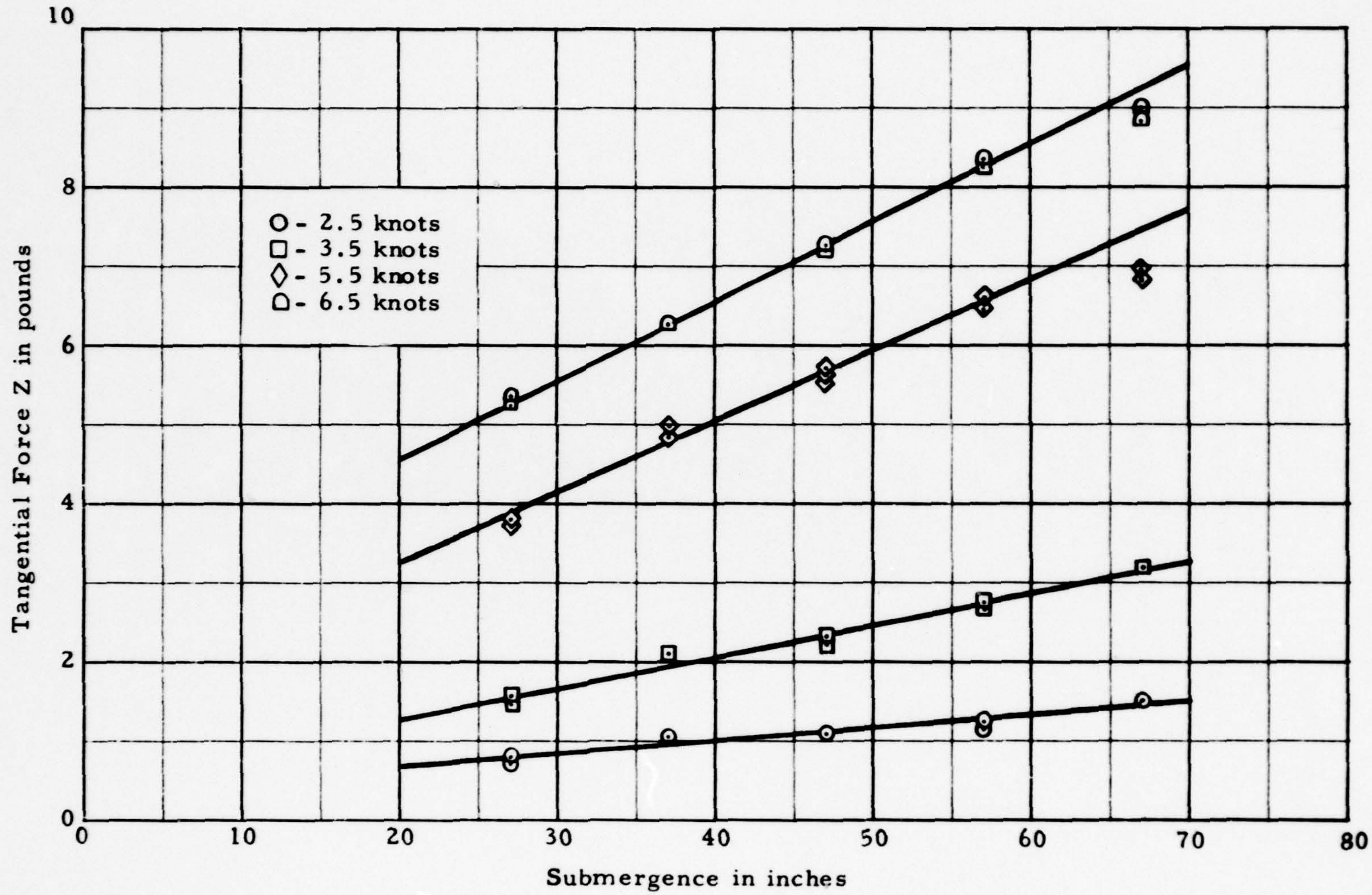

Figure 4 - Tangential Force Versus Submergence for a Cable Angle of 55.10 Degrees

TABLE 4

Values of Normal and Tangential Loading Functions

Cable Angle, degrees	Normal X/X_{90}							
	Speed, knots							
	2.5	3.0	3.5	4.0	5.0	5.5	6.0	6.5
30.40	0.315	0.319	0.311	0.289	0.278	0.295	0.279	0.274
35.30	0.384	0.325	0.355	0.326	0.328	0.347	0.339	0.342
40.30	0.426	0.448	0.410	0.415	0.412	0.408	0.410	0.418
45.20	0.465	0.514	0.473	0.485	0.479	0.487	0.493	0.484
50.10	0.586	0.586	0.568	0.559	0.555	0.576	0.559	0.565
55.10	0.636	0.644	0.601	0.619	0.612	0.638	0.619	0.636
60.10	0.747	0.743	0.729	0.708	0.721	0.736	0.710	0.721
64.85	0.807	0.804	0.786	0.781	0.796	0.812	0.802	0.800
69.85	0.878	0.852	0.845	0.819	0.827	0.867	0.824	0.841
74.80	0.914	0.907	0.908	0.884	0.895	0.923	0.895	0.899
79.70	0.958	0.943	0.952	0.915	0.923	0.963	0.931	0.960
84.70	0.996	0.990	0.994	0.978	0.970	0.981	0.973	0.985
89.94	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Cable Angle, degrees	Tangential Z/X_{90}							
	Speed, knots							
	2.5	3.0	3.5	4.0	5.0	5.5	6.0	6.5
30.40	0.225	0.222	0.225	0.223	0.221	0.223	0.222	0.222
35.30	0.234	0.237	0.238	0.233	0.238	0.241	0.238	0.240
40.30	0.234	0.230	0.228	0.225	0.225	0.223	0.222	0.224
45.20	0.234	0.230	0.228	0.225	0.225	0.225	0.223	0.226
50.10	0.212	0.207	0.206	0.204	0.203	0.205	0.203	0.203
55.10	0.202	0.207	0.206	0.204	0.187	0.210	0.208	0.210
60.10	0.170	0.170	0.168	0.170	0.171	0.172	0.171	0.173
64.85	0.148	0.148	0.152	0.150	0.150	0.151	0.151	0.152
69.85	0.138	0.141	0.141	0.141	0.141	0.142	0.141	0.142
74.80	0.096	0.096	0.097	0.091	0.091	0.091	0.091	0.091
79.70	0.085	0.081	0.081	0.079	0.077	0.078	0.078	0.078
84.70	0.053	0.051	0.048	0.050	0.048	0.046	0.046	0.048
89.94	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The values for the normal loading function are plotted in Figure 5 and for the tangential loading function in Figure 6. Superimposed on each of the respective figures is the curve of the mathematical expression for the loading function. The curve-fitting process to obtain the mathematical expressions consisted of generating a group of least-square curves for each set of loading values using the BVPDE3 program and selected combinations of terms in the trigonometric series,

$$A_0 + A_1 \cos \varphi + B_1 \sin \varphi + A_2 \cos 2\varphi + B_2 \sin 2\varphi,$$

for which the loading boundary conditions are satisfied. Then, using the CMPFN2 program, the curves in each group were compared with each group of values to determine the best form for each loading function. The resulting mathematical expressions for the loading functions, neglecting any Reynolds number effect, are

$$\Lambda(\varphi) = -0.5550 + 0.7733 \cos \varphi + 1.3367 \sin \varphi - 0.2183 \cos 2\varphi - 0.4505 \sin 2\varphi \qquad [1]$$

and

$$\Gamma(\varphi) = -0.3544 + 0.4305 \cos \varphi + 0.3862 \sin \varphi + 0.0318 \cos 2\varphi \qquad [2]$$

where Λ and Γ are the normal (X/X_{90}) and tangential (Z/X_{90}) loading functions, respectively. Boundary conditions for the functions are as follows:

$$\Lambda(0) = 0 \quad \Lambda(90) = 1 \text{ and } \Gamma(90) = 0 \qquad [3]$$

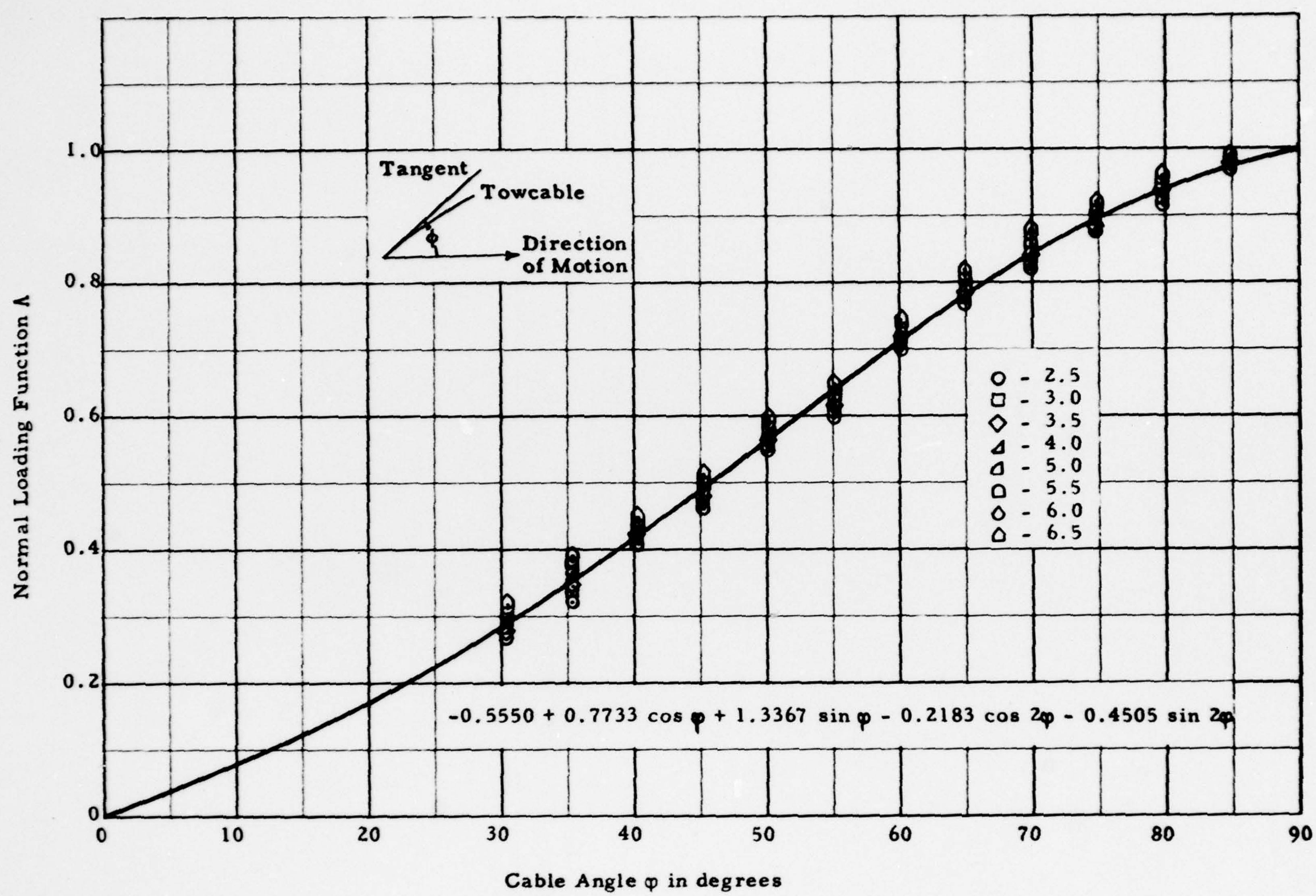

Figure 5 - Normal Loading Function Versus Cable Angle

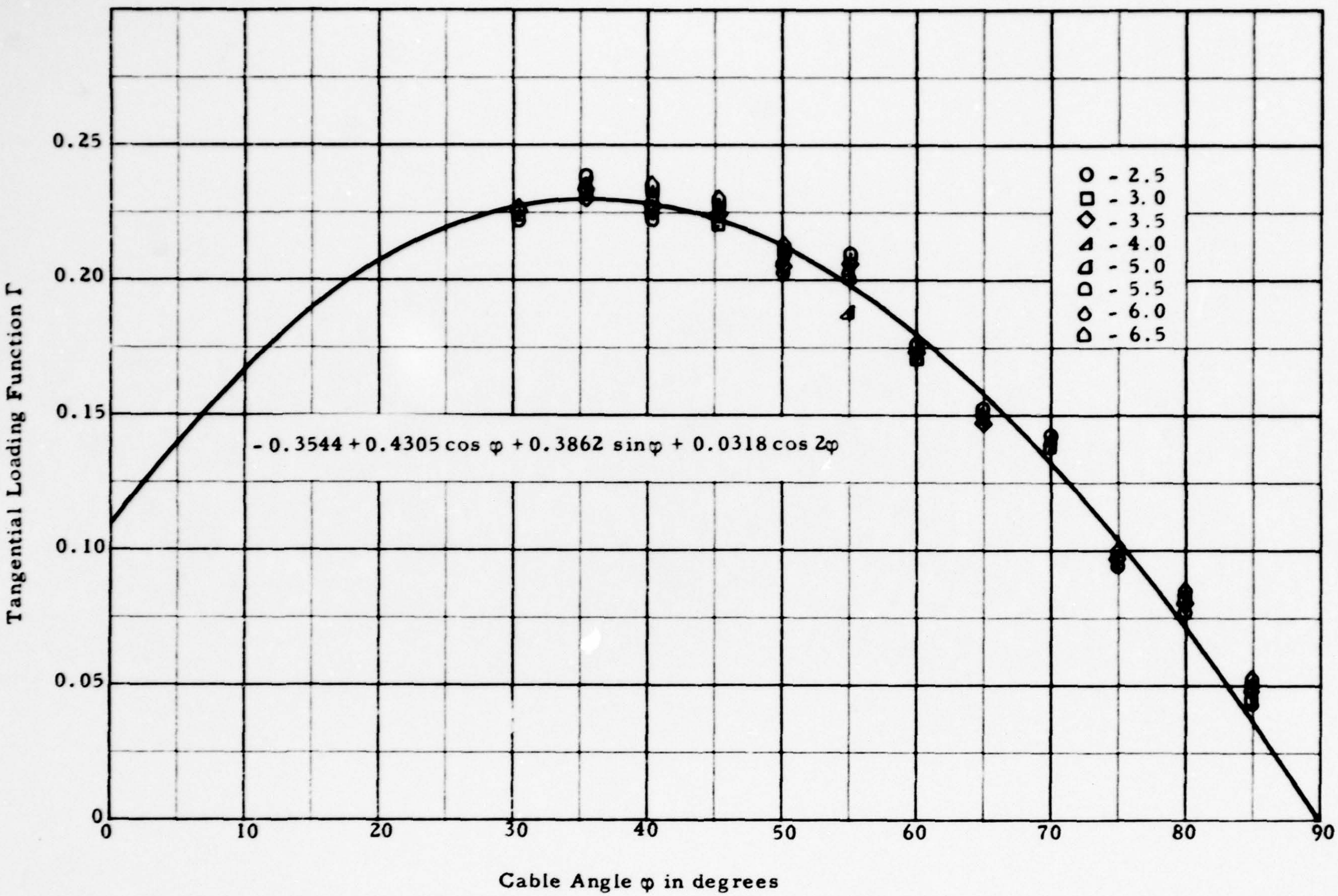

Figure 6 - Tangential Loading Function Versus Cable Angle

DRAG COEFFICIENT

The drag coefficient C_R and corresponding Reynolds number R_d were calculated for each speed using the following expressions:

$$C_R = \frac{R}{\frac{1}{2}\rho d V^2} \qquad [4]$$

and

$$R_d = \frac{Vd}{\nu} \qquad [5]$$

where

d is the cable diameter,

R is the drag per unit length of cable when the cable is normal to the stream and is equal to the slope $\frac{\Delta X}{\Delta s}$ of the force-submergence plot at φ = 90 degrees, ($R \equiv X_{90}$),

s is the distance along the cable (submergence),

V is the speed,

ρ is the mass density of fresh water at 71 degrees F, and

ν is the kinematic viscosity of fresh water at 71 degrees F.

The calculated drag coefficients are plotted in Figure 7 as a function of Reynolds number.

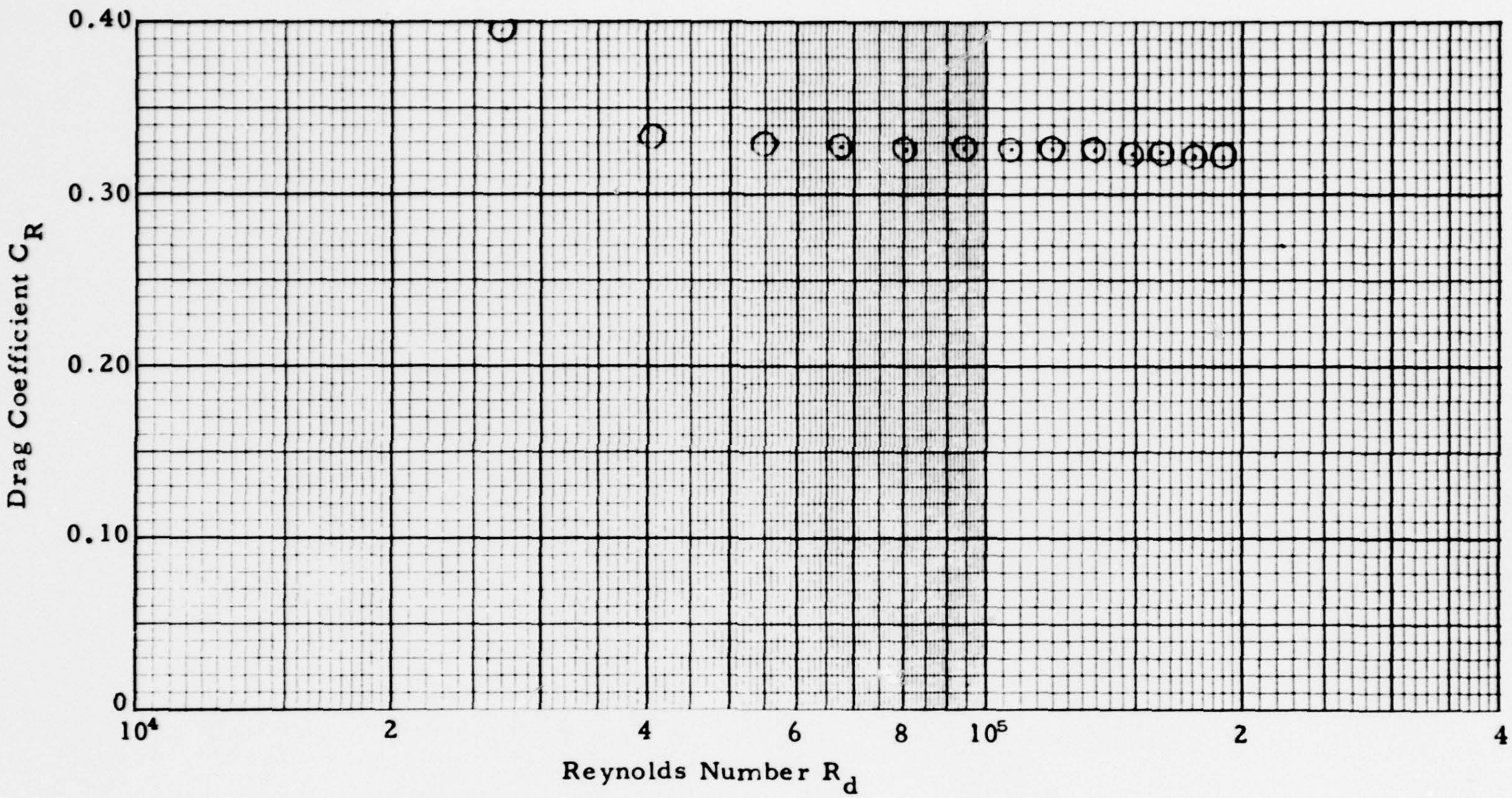

Figure 7 - Drag Coefficient as a Function of Reynolds Number

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